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Changing Volumes, Risk Profiles, and Outcomes of Coronary Artery Bypass Grafting and Percutaneous Coronary Interventions

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Background. This study analyzed and quantified perceptions that evolving percutaneous coronary intervention technologies changed referral patterns of patients with coronary artery disease and adversely impacted volumes, risk profiles, and outcomes of patients undergoing coronary artery bypass grafting surgery (CABG).

Methods. Washington State's prospective clinical registry was used to analyze volumes, risk profiles, and outcomes of all patients undergoing isolated CABG and percutaneous coronary intervention.

Results. A total of 154,602 revascularization procedures were performed between 1999 and 2007. Total revascularizations procedures (percutaneous coronary intervention plus CABG) increased by 32% (from 14,084 in 1999 to 18,620 in 2007). Compared with 1999, by 2007 CABG volume decreased by 37%, while percutaneous coronary intervention volume increased by 71%. The ratio of percutaneous coronary intervention to CABG increased by 2.7-fold from 1.7:1 to 4.6:1 ($p < 0.0001$). Three time intervals were compared (1999–2000, 2001–2003, 2004–2007). For patients undergoing CABG, the prevalence of diabetes (28% to 36%), hypertension (66% to 76%), and three-vessel or left main disease (57% to 68%) increased significantly ($p < 0.0001$ for all). Female sex (28% to 24%), congestive failure (24% to 13%), and smoking (64% to 59%) decreased significantly ($p < 0.0001$ for all), whereas patients' age, low ejection fraction, and use of intraaortic balloon pump were unchanged. Although mortality (2.4% to 2.2%; $p = 0.79$), return to the operating room (3.4% to 3.6%; $p = 0.41$), and need for postoperative hemodialysis (1.2% to 1.0%; $p = 0.44$) were unchanged, the incidences of stroke (1.9% to 1.3%; $p = 0.01$), myocardial infarction (1.7% to 0.8%; $p < 0.0001$), transfusion (40% to 34%; $p < 0.0001$), and extubation within 6 hours (43% to 60%; $p < 0.0001$) improved significantly in the past 9 years.

Conclusions. Despite significant reduction in both the volume and ratio of patients referred for surgical revascularization, risk profiles of patients undergoing isolated CABG in Washington State changed only modestly. Coronary artery bypass grafting mortality was not adversely affected, and morbidity was reduced.

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Coronary revascularization, with either percutaneous coronary intervention (PCI) or coronary artery bypass grafting (CABG) compared with medical therapy, relieves symptoms and, for some patient subsets, prolongs life [1–3]. In selected studies and patients when both revascularization strategies could be applied, PCI and CABG demonstrated similar outcomes with respect to death and myocardial infarction (MI), but there was less angina relief and more repeat interventions with PCI [4–11]. In specific higher risk patients (diabetes mellitus [DM], three-vessel coronary artery disease [CAD], depressed left ventricular function), CABG confers a survival advantage and lower MI rates [7, 8, 12–16]. More recent advances in PCI technologies with drug-eluting stents (DES) coupled with intensified medical therapy decreased risk of coronary reintervention [17–21] but were associated with an increased stent thrombosis risk that requires longer term intense antiplatelet therapy [22–25]. Although direct comparisons of PCI to CABG with arterial revascularization are limited by the specific population subsets, small sample size, and relatively short follow-up, PCI with DES is applied to a progressively broader patient population with multivessel CAD. These changing referral patterns may alter risk profiles, characteristics, and outcomes of established CABG and PCI. This study aimed to evaluate and quantify widely held perceptions that advances in PCI with DES and changing referral patterns adversely impacted risk profiles and outcomes of patients undergoing CABG or PCI.

Material and Methods

Clinical Outcomes Assessment Program

The Clinical Outcomes Assessment Program (COAP) of the state of Washington is a comprehensive quality improve-

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ment program that was begun in 1997 as a collaborative effort between the Washington State Health Care Authority, physicians, and hospitals providing cardiac care across the state [26]. The COAP is now sponsored by the Foundation for Health Care Quality, a 501c(3) not-for-profit entity that facilitates public-private partnerships in health care and is governed by a management committee composed of cardiac surgeons, cardiologists, and members from administrative and quality improvement fields.

To measure quality, the COAP has a comprehensive prospective database of all coronary revascularization (PCI and CABG) procedures performed in the state. Follow-up is limited to the hospital stay for the revascularization procedure. Volumes, risk profiles, and outcomes of all patients undergoing isolated CABG and PCI in the state of Washington from 1999 through 2007 were carefully evaluated (University of Washington Medical Center IRB No. 28604).

Statistical Methods

Revascularization status was defined as (1) no prior revascularization (NPR), (2) prior PCI, or (3) prior CABG. To compare patient characteristics and outcomes across these three groups, the χ^2 statistic was used for categorical variables and the one-way analysis of variance was used for age, number of grafts, and postprocedure length of stay. We also compared types of procedures, patient characteristics, and outcomes for three time periods: (1) 1999 through 2000, (2) 2001 through 2003, and (3) 2004 through 2007. The last period was selected to specifically reflect the impact of DES. The χ^2 for trend statistic was used for categorical variables, and a linear trend statistic was used for continuous variables such as age.

Because preprocedural risk profiles differ among revascularization groups and as a function of time, to more accurately compare changes in outcomes during the study's different time periods and to assess the independent effects of revascularization status, multivariate regression models were used to determine the association between prior revascularization status and outcome, and separately in patients with NPR, to assess changing outcomes as a function of time. A common set of predictors of mortality and morbidity was used; for CABG they were age in years, male sex, ejection fraction less than 0.30, creatinine greater than 2.0 mg/dL, preoperative balloon pump, emergency priority, history of congestive heart failure, history of chronic obstructive pulmonary disease, history of cerebrovascular disease, and the number of diseased vessels. For PCI, in addition to these variables, cardiogenic shock on admission and history of peripheral vascular disease were also used. After these variables were entered into the model, history of prior revascularization, defined as yes or no, was forced into the model to determine its association with outcome. Logistic regression was used for all categorical outcomes (mortality or morbidity), and linear regression was used for the single continuous outcome (postprocedure length of stay). Similar analyses were performed using time period (1999–2000, 2001–2003, 2004–2007), which was forced in after the common set of predictors was entered into the model.

The large number of procedures in the COAP database resulted in even small differences being statistically significant. More attention should be paid to the magnitude of the differences and to trends rather than the probability value.

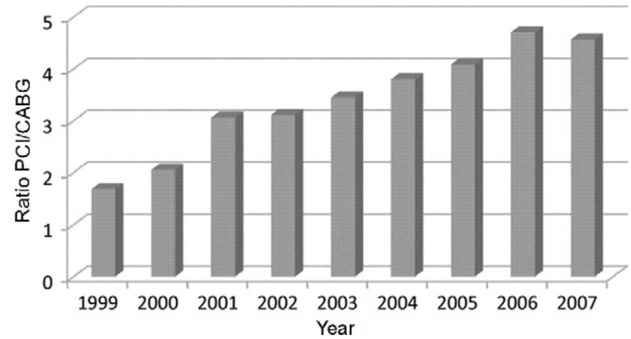

Fig 2. Ratio of all percutaneous coronary intervention (PCI) to coronary artery bypass grafting (CABG) by year.

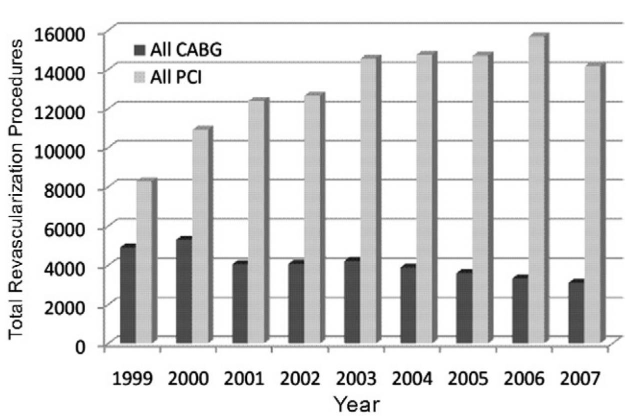

Fig 1. All coronary artery bypass grafting (CABG) and percutaneous coronary intervention (PCI) procedures per year.

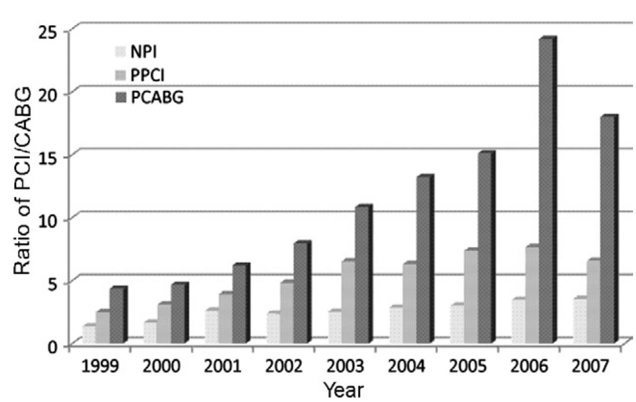

Fig 3. Ratio of all percutaneous coronary intervention (PCI) to coronary artery bypass grafting (CABG) by prior revascularization. (NPI = no prior intervention; PCABG = prior CABG; PPCI = prior PCI.)

Results

A total of 154,602 revascularization procedures (CABG and PCI) were performed between 1999 and 2007. Compared with 1999, by 2007 total CABG volume decreased by 37% (from 4,908 to 3,098), while total PCI volume increased by 71% (from 8,276 to 14,161; Fig 1). For all procedures, the ratio of PCI to CABG increased by 2.7-fold ($p < 0.0001$) from 1.7:1 to 4.6:1 (Fig 2). During the study's 9-year interval, the ratio of PCI to CABG increased to similar levels in patients with NPR and for those with prior PCI (2.6-fold; $p < 0.001$) but rose most dramatically in patients with prior CABG procedures (4.7-fold; $p < 0.0001$), reaching a ratio of 18:1 by 2007 (Fig 3).

For the entire study period (1999 through 2007), the incidence, characteristics, and outcomes of patients with NPR undergoing CABG or PCI are compared with those undergoing repeat procedures after prior CABG and PCI.

Risk profiles for all patients undergoing CABG are compared in Table 1. Compared with patients with NPR, those with prior PCI undergoing CABG were slightly younger (by 2 years; $p < 0.0001$), had less extensive CAD (left main [LM] or three-vessel disease [3VD]: 55% versus 66%; $p < 0.0001$), more use of intraaortic balloon pump (6.2% versus 5.4%; $p < 0.0001$), and higher incidence of cardiogenic shock (3.4% versus 2.0%; $p < 0.0001$). Left ventricular ejection fraction was unaffected by prior PCI. Patients requiring repeat (redo) CABG were older (by 2 years compared with CABG NPR and by 4 years compared with CABG with prior PCI; $p < 0.0001$), with significantly increased comorbidities (congestive heart failure, cerebral and peripheral disease, smoking, angina class, intraaortic balloon pump, LM/3VD, and lower ejection fraction; $p < 0.0001$). Unexpectedly, in this highest risk group of repeat CABG were lower incidences of female sex (18% versus 25%; $p < 0.0001$) and DM (30% versus 32%; $p < 0.0001$). After correcting for differences in preprocedural risk characteristic by multivariate analysis, morbidity and mortality rates for patients undergoing CABG with NPR or prior PCI were similar (Table 2). However, compared with patients undergoing CABG with prior PCI or those with NPR, patients undergoing repeat CABG procedures had nearly a threefold increased mortality (6.32% versus 2.0% and 2.3%; $p < 0.0001$) and MI rates (3.7% versus 1.2% and 1.2%; $p < 0.0001$), and double the incidence of renal failure requiring hemodialysis (2.6% versus 1.2% and 1.1%; $p < 0.0001$; Table 2). Perioperative reoperations for bleeding, prolonged intubation, transfusion rates, and ventilator support times were also significantly higher ($p < 0.003$ for all). Extent of revascularization (number of vessels bypassed) was lowest in patients undergoing repeat CABG (3.0 ± 1.3 versus 3.4 ± 1.2 and 3.5 ± 1.2 grafts; $p < 0.0001$).

The incidence of off-pump CABG for NPR peaked in 2003 at 29% and has fallen dramatically since then in both total procedures as well as percent of CABG procedures performed (19% for 2007).

Drug-eluting stent technology was clinically introduced in 2003. Use rose dramatically to 78% of all PCI interventions by 2004 ($p < 0.0001$), peaked at 88% by 2005, and decreased to 67% by 2007 ($p < 0.0001$).

For all patients undergoing PCI, risk profiles of patients with NPR and those with prior PCI were similar but with a significant increase in elective procedures (65% versus 47%; $p < 0.0001$), decrease in emergency procedures (12% versus 26%; $p < 0.0001$), and acute MI interventions (14% versus 30%; $p < 0.0001$) in patients undergoing PCI with history of prior PCI (Table 3). Even after correcting for differences in patient risk profiles with multivariate analyses, a significantly lower mortality for repeat PCI compared with NPR PCI was noted (0.9% versus 1.8%; $p < 0.0001$; Table 4). Patients undergoing PCI after prior CABG had significantly increased comorbidities (age, lower ejection fraction, DM, and cerebral and peripheral vascular disease; $p < 0.0001$) and more extensive CAD (incidence of 3VD/LM 61% versus 11% to 13%; $p < 0.0001$), but were less emergent (9% versus 12% to 26%; $p < 0.0001$). Despite significant differences in extent of multivessel CAD, extent of revascularization (numbers of vessels treated) was comparable in all three PCI treatment groups (1.2 ± 0.6 vessels; Table 3). Again, even after adjustment for differences in patient risk profiles and characteristics, mortality and morbidity for PCI after CABG was intermediate. The lowest mortality was noted for repeat PCI (0.9%), intermediate for PCI after CABG (1.3%), and highest for PCI with NPR (1.8%; $p < 0.0001$; Table 4). These analyses were repeated by eliminating emergency cases. In patients undergoing CABG, outcomes for those with NPR and those with prior PCI were similar with marked increase in morbidity and mortality (twofold to threefold) in patients undergoing repeat CABG (Table 5). Mortality rates for PCI were lowest in patients with prior PCI but similar for PCI with NPR or prior CABG (0.4% versus 0.8%; $p < 0.0001$; Table 6).

In patients with prior revascularization (either PCI or CABG), it is not possible from this data set to define the severity of residual or current CAD at the time of the most recent coronary reintervention as native disease burden may have remained partially revascularized. Because extent of CAD profoundly influences risk and choice of therapy, analyses of temporal trends during the 9 years of the study were therefore limited to patients undergoing either CABG or PCI with NPR. Temporal changes were assessed for three time periods: 1999 through 2000, 2001 through 2003, and 2004 through 2007, and are noted for CABG with NPR in Tables 7 and 8 and for PCI with NPR in Tables 9 and 10.

For patients undergoing CABG (NPR), the incidence of DM (28% to 36%), hypertension (66% to 76%), and 3VD/ LM disease (57% to 68%) increased significantly ($p < 0.0001$ for all). Other known risk factors such as female sex (28% to 24%), congestive heart failure (24% to 13%), and smoking (64% to 59%) decreased significantly ($p < 0.0001$). Finally some risk factors such as patient age (66 ± 11 years) and use of intraaortic balloon pump (5.3% to 5.6%) were unchanged (Table 7). Coronary artery bypass grafting mortality (2.4% to 2.2%; $p = 0.79$), return to the operating room (3.4% to 3.6%; $p = 0.41$), and need for postoperative hemodialysis (1.2% to 1.0%; $p = 0.44$) were unchanged, whereas the incidences of stroke (1.9% to 1.3%; $p = 0.014$), MI (1.7% to 0.8%; $p <$

Table 1. Risk Profiles by Prior Revascularization Status: All Coronary Artery Bypass Grafting

Variable	NPR (n = 27,250)	Prior PCI (n = 6,899)	Prior CABG (n = 2281)	*p* Value
Age (y)	66 ± 11	64 ± 11	68 ± 9	<0.0001
Women	25%	25%	18%	<0.0001
Hx CHF	18%	16%	22%[a]	<0.0001
Hx HTN	72%	76%	76%	<0.0001
Hx DM	32%	33%	30%	0.013
On insulin/oral medications	27%	28%	24%	0.002
Hx lung disease	15%	15%	14%	0.95
Hx cerebrovascular disease	13%	12%	18%	<0.0001
Hx peripheral vasc disease	15%	14%	20%	<0.0001
Hx cigarette smoking	61%	64%	67%	<0.0001
Canadian class[b]				<0.0001
No angina	13%	10%	8%	
I	3%	2%	3%	
II	15%	12%	12%	
III	40%	39%	40%	
IV	30%	36%	37%	
LV ejection fraction				<0.0001
<0.30	6%	5%	8%	
0.30–0.49	25%	27%	34%	
>0.50	69%	68%	58%	
Number diseased vessels				<0.0001
1	10%	17%	10%	
2	24%	28%	21%	
3	62%	51%	67%	
LM lesion > 50%	29%	24%	30%	<0.0001
LM > 50% or 3VD	66%	55%	68%	<0.0001
LAD lesion > 70%	79%	74%	80%	<0.0001
Procedure priority				<0.0001
Elective	54%	54%	61%	
Urgent	41%	38%	34%	
Emergent	5%	7%	4%	
Salvage	<1%	1%	1%	
Balloon pump	5.4%	6.2%	8.4%	<0.0001
Cardiogenic shock	2.0%	3.4%	2.3%	<0.0001
Number grafts	3.5 ± 1.2	3.4 ± 1.2	3.0 ± 1.3	<0.0001

CABG = coronary artery bypass grafting; CHF = congestive heart failure; DM = diabetes mellitus; HTN = hypertension; Hx = history; LAD = left anterior descending coronary artery; LM = left main; LV = left ventricular; NPR = no prior revascularization; PCI = percutaneous coronary intervention; 3VD = three-vessel disease.

Table 2. Outcomes: All Coronary Artery Bypass Grafting

Variable	NPR (n = 27,250)	Prior PCI (n = 6,899)	Prior CABG (n = 2,281)	Adjusted *p* Value[a]
Hospital death	2.3%	2.0%	6.3%	<0.0001
Postoperative stroke	1.6%	1.3%	2.1%	0.96
Postoperative dialysis	1.1%	1.2%	2.6%	0.001
Postoperative myocardial infarction	1.2%	1.2%	3.7%	<0.0001
Postprocedure length of stay (days)	6.0 ± 5.2	5.8 ± 5.0	6.7 ± 5.9	0.22
Return to operating room for any reason	3.5%	4.0%	6.2%	0.001
Red blood cell transfusion	38%	36%	50%	<0.0001
Ventilator time < 6 hours	55%	56%	46%	0.003

[a] Adjusted by multivariate regression model

CABG = coronary artery bypass grafting; NPR = no prior revascularization; PCI = percutaneous coronary intervention.

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Table 3. Risk Profiles by Prior Revascularization Status: All Percutaneous Coronary Intervention

Variable	NPR (n = 68,134)	Prior PCI (n = 28,856)	Prior CABG (n = 21,089)	p Value
Age (y)	64 ± 12	64 ± 12	69 ± 11	<0.0001
Women	32%	30%	24%	<0.0001
Hx CHF	8%	10%	17%[a]	<0.0001
Hx HTN	63%	74%	78%	<0.0001
Hx DM	23%	28%	35%	<0.0001
On insulin/oral medications	18%	24%	30%	<0.0001
Hx lung disease	11%	13%	13%	<0.0001
Hx cerebrovascular disease	8%	10%	17%	<0.0001
Hx peripheral vasc disease	8%	11%	20%	<0.0001
Hx cigarette smoking	58%	59%	58%	0.007
Canadian class[b]				<0.0001
No angina	16%	14%	12%	
I	4%	5%	4%	
II	14%	18%	16%	
III	28%	33%	36%	
IV	38%	29%	32%	
LV ejection fraction				<0.0001
<0.30	4%	4%	8%	
0.30–0.49	20%	19%	28%	
>0.50	76%	77%	64%	
Number diseased vessels				<0.0001
1	57%	58%	18%	
2	28%	28%	21%	
3	13%	11%	60%	
LM lesion > 50%	2%	2%	22%	<0.0001
LM > 50% or 3VD	13%	11%	61%	<0.0001
LAD lesion > 70%	55%	50%	76%	<0.0001
Procedure priority				<0.0001
Elective	47%	65%	64%	
Urgent	26%	23%	26%	
Emergent	26%	12%	9%	
Salvage	<1%	<1%	<1%	
Balloon pump	1.0%	0.6%	1.0%	<0.0001
Cardiogenic shock	3.2%	1.6%	1.6%	<0.0001
Procedure performed for MI	30%	14%	11%	<0.0001
Number vessels attempted	1.2 ± 0.6	1.2 ± 0.6	1.2 ± 0.6	<0.0001

CABG = coronary artery bypass grafting; CHF = congestive heart failure; DM = diabetes mellitus; HTN = hypertension; Hx = history; LAD = left anterior descending coronary artery; LM = left main; LV = left ventricular; NPR = no prior revascularization; PCI = percutaneous coronary intervention; 3VD = three-vessel disease.

Table 4. Outcomes: All Percutaneous Coronary Intervention

Variable	NPR (n = 68,134)	Prior PCI (n = 28,856)	Prior CABG (n = 21,089)	Adjusted p Value[a]
Hospital death	1.8%	0.9%	1.3%	<0.0001
Postoperative stroke	0.3%	0.2%	0.3%	0.35
Postoperative dialysis	0.3%	0.2%	0.3%	0.19
Postprocedure length of stay (days)	2.2 ± 3.4	1.7 ± 2.6	1.9 ± 2.9	<0.0001
Return to operating room for any reason	1.5%	1.2%	0.9%	<0.0001
Unplanned CABG same admission (primary PCI)	0.4%	0.5%	0.1%	0.030
Unplanned CABG same admission (nonprimary PCI)	0.2%	0.1%	0.1%	<0.0001

[a] Adjusted by multivariate regression model.

CABG = coronary artery bypass grafting; NPR = no prior revascularization; PCI = percutaneous coronary intervention.

Table 5. Outcomes: Coronary Artery Bypass Grafting (Emergent Cases Excluded)

Variable	NPR (n = 25,539)	Prior PCI (n = 6,388)	Prior CABG (n = 2,183)	Adjusted *p* Value[a]
Hospital death	2.0%	1.6%	5.8%	<0.0001
Postoperative stroke	1.5%	1.3%	2.1%	0.78
Postoperative dialysis	1.1%	1.0%	2.4%	0.004
Postoperative myocardial infarction	1.2%	1.1%	3.7%	<0.0001
Postprocedure length of stay (days)	5.9 ± 5.1	5.7 ± 4.7	6.6 ± 5.8	0.29
Return to operating room for any reason	3.3%	3.6%	6.0%	0.004
Red blood cell transfusion	38%	36%	50%	<0.0001
Ventilator time < 6 hours	57%	58%	47%	0.003

[a] Adjusted by multivariate regression model.

CABG = coronary artery bypass grafting; NPR = no prior revascularization; PCI = percutaneous coronary intervention.

0.0001), transfusion (40% to 34%; $p < 0.0001$), and extubation within 6 hours (43% to 60%; $p < 0.0001$) improved significantly during these three time intervals (Table 8).

Owing to larger numbers, temporal changes were even more significant in patients undergoing PCI with NPR (Table 9), with increased acuity and severity of many known comorbidities. There was a modest increase in age (63 ± 12 to 64 ± 12 years; $p < 0.0001$), cerebral vascular disease (7% to 8%; $p < 0.0001$), DM (20% to 25%; $p < 0.0001$), Canadian heart class (III and IV, 58% to 70%; $p < 0.0001$), and LM/3VD (11% to 14%; $p < 0.0001$). Unexpectedly, there was an improvement in cardiogenic shock (3.7% to 3.0%; $p = 0.001$). Very significant and much more dramatic was an increase in PCI for acute MI (24% to 33%; $p < 0.0001$). Clinical outcomes for PCI remained stable and unchanged despite marked increase in patient acuity with a decreased return to the operating room for any reason from 1.7% to 1.3% (adjusted p value < 0.0001; Table 10).

Although the percent of 3VD or LM CAD in patients with NPR treated with PCI increased only modestly (11% to 14%; $p < 0.0001$; Table 9), because of the disproportionate ratio of PCI to CABG this underestimates the prevalence of this therapy in patients with high CAD burdens. Of all the 26,571 patients with NPR who underwent revascularization procedures for LM/3VD (Tables 7, 9) the percent treated with PCI increased from 22.8% in 1999 through 2000, to 38.1% in 2004 through 2007 ($p <$ 0.0001). The percent of patients with NPR with DM and LM/3VD treated by PCI was 26.4% for the entire study.

Broader application of PCI profoundly impacted CABG volume. By 2007, the number of patients undergoing PCI after a prior CABG (2,483) exceeded the number of patients undergoing CABG with NPR (2,260) and approached the overall number of CABG procedures performed (3,098).

Comment

Washington State's COAP database captures all revascularization procedures (CABG and PCI) and therefore allows us to carefully note temporal changes in patient profiles and outcomes. Significant changes in CABG and PCI and volumes were noted in the past 9 years with a dramatic fall in CABG procedures (37%) and increase in PCI volumes (71%) accompanied by a dramatic rise in the ratio of PCI to CABG by 2.7-fold to a current ratio of 4.6:1. The total number of revascularization procedures (CABG plus PCI) per year increased by 32% (14,084 in 1999 to 18,620 in 2007). Most of the PCI growth occurred in patients with NPR (46%) and prior PCI (38%). Growth in PCI volumes were disproportionate to the fall in CABG volumes and to the 8.5% increase in the state's population from 5.9 million in 2000 to 6.4 million in 2006 during the study period [27]. Growth of PCI preceded the

Table 6. Outcomes: Percutaneous Coronary Intervention (Emergent Cases Excluded)

Variable	NPR (n = 49,647)	Prior PCI (n = 25,038)	Prior CABG (n = 19,000)	Adjusted *p* Value[a]
Hospital death	0.8%	0.4%	0.8%	<0.0001
Postoperative stroke	0.2%	0.1%	0.3%	0.14
Postoperative dialysis	0.2%	0.1%	0.2%	0.033
Postprocedure length of stay (days)	1.7 ± 2.6	1.5 ± 2.3	1.7 ± 2.6	<0.0001
Return to operating room for any reason	1.2%	0.9%	0.8%	<0.0001
Unplanned CABG same admission (primary PCI)	0.4%	0.5%	0.2%	0.29
Unplanned CABG same admission (nonprimary PCI)	0.2%	0.1%	0.1%	<0.0001

[a] Adjusted by multivariate regression model.

CABG = coronary artery bypass grafting; NPR = no prior revascularization; PCI = percutaneous coronary intervention.

Table 7. Changes in Risk Profiles of Coronary Artery Bypass Grafting (No Prior Revascularization)

Variable	1999–2000 (n = 7,644)	2001–2003 (n = 9,008)	2004–2007 (n = 10,598)	Total (n = 27,250)	*p* Value
Age (y)	66 ± 11	66 ± 11	66 ± 11	66 ± 11	0.10
Women	28%	25%	24%	25%	<0.0001
Hx CHF	24%	18%	13%[a]	18%	<0.0001
Hx HTN	66%	71%	76%	72%	<0.0001
Hx DM	28%	32%	36%	32%	<0.0001
On insulin/oral medications	23%	27%	29%	27%	<0.0001
Hx lung disease	13%	15%	15%	15%	<0.0001
Hx cerebrovascular disease	13%	13%	13%	13%	0.77
Hx peripheral vasc disease	14%	15%	16%	15%	0.002
Hx cigarette smoking	64%	61%	59%	61%	<0.0001
Canadian class[b]					0.008
No angina	13%	14%	12%	13%	
I	4%	3%	3%	3%	
II	15%	15%	15%	15%	
III	39%	39%	41%	40%	
IV	29%	30%	30%	30%	
LV ejection fraction					0.006
<0.30	6%	6%	6%	6%	
0.30–0.49	26%	25%	24%	25%	
>0.50	68%	68%	70%	69%	
Number diseased vessels					<0.0001
1	8%	3%	2%	4%	
2	11%	8%	11%	10%	
3	26%	23%	23%	24%	
LM lesion > 50%	55%	66%	63%	62%	
LM > 50% or 3VD	24%	30%	32%	29%	<0.0001
LAD lesion > 70%	57%	69%	68%	66%	<0.0001
Procedure priority	75%	81%	79%	79%	<0.0001
Elective					0.002
Urgent	55%	54%	52%	54%	
Emergent	39%	40%	44%	41%	
Salvage	6%	5%	4%	5%	
Balloon pump	<1%	<1%	<1%	<1%	
Age (y)	5.3%	5.2%	5.6%	5.4%	0.40
Cardiogenic shock	2.1%	1.6%	2.2%	2.0%	0.01

[a] Possible problems with coding of CHF variable in 2004. [b] Not collected in 2006 or 2007.

CABG = coronary artery bypass grafting; CHF = congestive heart failure; DM = diabetes mellitus; HTN = hypertension; Hx = history; LAD = left anterior descending coronary artery; LM = left main; LV = left ventricular; NPR = no prior revascularization; PCI = percutaneous coronary intervention; 3VD = three-vessel disease.

introduction of DES in 2004 and was most dramatic between 1999 and 2003. Decreased need for repeat PCI with DES and the more recent challenge to the assumed superiority of PCI compared with intensified medical therapy with lifestyle changes (optimal medical therapy) in patients with stable coronary syndromes [25] may significantly impact and perhaps reverse PCI growth. The PCI volume seemed to have flattened by 2004 to 2005 and actually fell by 9.6% from 2006 to 2007. Our data suggest a wider embrace of PCI as the primary treatment for acute coronary syndromes, with a dramatic rise in incidence of PCI in those patients as a function of time as noted by a marked increase in acute, emergency PCI interventions now surpassing 30% of PCI in patients with NPR. This resulted in an unanticipated increased morbidity (return to operating room, length of stay, unplanned CABG; adjusted $p < 0.03$ for all) and mortality (adjusted $p < 0.0001$) in patients undergoing PCI with no prior revascularization compared with those undergoing PCI after prior PCI or CABG.

Also noted was a dramatic fall (>60%) in patients undergoing repeat CABG procedures with a rise in the ratio of patients undergoing PCI after prior CABG by 4.7-fold during the study period to a current ratio of PCI to repeat CABG of 18:1. It seems that regardless of patients' risk profiles (such as DM, low ejection frac-

Table 8. Outcomes: Coronary Artery Bypass Grafting (No Prior Revascularization)

Variable	1999–2000 (n = 7,644)	2001–2003 (n = 9,008)	2004–2007 (n = 10,598)	Total (n = 27,250)	Adjusted *p* Value[a]
Hospital death	2.4%	2.3%	2.2%	2.3%	0.79
Postoperative stroke	1.9%	1.6%	1.3%	1.6%	0.014
Postoperative dialysis	1.2%	1.1%	1.0%	1.1%	0.44
Postoperative myocardial infarction	1.7%	1.1%	0.8%	1.2%	<0.0001
Postprocedure length of stay (days)	5.9 ± 5.2	5.9 ± 5.0	6.1 ± 5.4	6.0 ± 5.2	0.028
Return to operating room for any reason	3.4%	3.4%	3.6%	3.5%	0.41
Red blood cell transfusion	40%	40%	34%	40%	<0.0001
Ventilator time < 6 hours	43%	55%	60%	55%	<0.0001

[a] Adjusted by multivariate regression model.

tion, prior MI, extent of CAD) or status of prior interventions (PCI or CABG), patients who require repeat revascularization are preferentially treated with PCI, with acceptable acute mortality and morbidity rates (highest morbidity and mortality for PCI with NPR, intermediate for PCI after prior CABG, and lowest for PCI after prior PCI).

The dramatic loss of CABG volume was associated with statistically significantly increases in risk profiles of patients undergoing isolated CABG in the state of Washington that reflect in part the large size of the study population. The clinical magnitude and significance of these changes appear variable and much more modest. Most importantly, these changes did not adversely impact surgical outcomes. Mortality was unchanged with decreased morbidity (cerebrovascular accident, MI, transfusion, ventilator time; adjusted $p < 0.01$ for all) reflecting technical advances, the State's quality outcomes initiatives, and perhaps patient selections (with more acute MI patients treated with PCI).

Risk profiles of patients undergoing PCI also increased during this time interval with a dramatic rise in emergency procedures, presumably reflecting a widely adopted practice of immediate revascularization for acute MI or unstable coronary syndromes now representing 33% of all PCI procedures in patients with NPR. This practice unexpectedly resulted in the highest mortality (double) and morbidity in patients undergoing PCI with no prior revascularization compared with patients with prior PCI even after adjustments for differences in preprocedural risk characteristics with multivariate analysis. Despite this, rates of acute PCI failure requiring emergency CABG were gratifyingly low (0.4% for primary or PCI for acute coronary syndrome, and 0.1% for nonprimary PCI) for the last 4 years of the study, supporting recent regional trends to relax prior requirement for on-site CABG backup.

Percutaneous coronary interventions and CABG are still applied to disparate patient populations. Even in the most recent 4 years of the study, after the wide use of DES, 66% of patients undergoing CABG have LM/3VD and receive a mean of 3.4 grafts. In contrast, for the same time interval, 14% of patients undergoing PCI had LM/3VD, and had 1.2 vessels treated on average ($p < 0.0001$). Despite a paucity of supporting studies and even conflicting clinical data [7, 8, 12–16, 28], PCI with DES is increasingly being applied to patients with high CAD burdens. Current American College of Cardiology Foundation Appropriateness Criteria Task Force, Society for Cardiovascular Angiography and Interventions, Society of Thoracic Surgeons, American Association for Thoracic Surgery, American Heart Association, and the American Society of Nuclear Cardiology 2009 appropriateness criteria for coronary revascularization deemed that evidence and data support appropriateness of CABG for LM and 3VD CAD [29]. In these patients, revascularization by CABG was appropriate and expected to improve patients' health outcomes and survival. These guidelines suggest that appropriateness of PCI for 3VD CAD was uncertain (may be acceptable and reasonable but more research or patient clinical information is needed to classify indication). For LM disease PCI was deemed inappropriate (not generally acceptable, unlikely to improve patients' health outcomes or survival) [29]. Despite these recommendations and prior 2005 guidelines [30], in the most recent 4 years of the study (2004 through 2007) the number of patients with DM treated with PCI was more than double those treated with CABG (8,460 versus 3,816). In all, 26.4% of patients with NPR with DM and LM/3VD were treated by PCI. Although the number of patients with NPR with LM or 3VD treated with CABG was significantly higher than those treated with PCI (17,713 versus 8,857) for the same period, it is surprising that 34% of patients were treated with PCI. This strongly suggests that current clinical practice varies widely from updated recommendations and seems to embrace a strategy of limited intervention of an isolated anatomic target lesion thought to be culpable for the patient's symptoms. It can be speculated that such a focused therapy is intended to decrease morbidity and mortality of initial interventions, but purposefully defers treatment of known residual concurrent coronary disease to future reinterventions. The long-term consequences of this departure from more complete revascularization strategies on mortality, cardiac morbidity, and costs are unknown, and are in conflict with the current published guidelines.

Study Limitations

The COAP database is limited to acute hospital outcomes after revascularization procedures and does not permit

Table 9. Changes in Risk Profiles of Percutaneous Coronary Intervention (No Prior Revascularization)

Variable	1999–2000 (n = 11,700)	2001–2003 (n = 22,593)	2004–2007 (n = 33,841)	Total (n = 68,134)	*p* Value
Age (y)	63 ± 12	64 ± 12	64 ± 12	64 ± 12	<0.0001
Women	34%	32%	32%	32%	<0.0001
Hx CHF	7%	9%	8%	8%	0.90
Hx HTN	55%	62%	67%	63%	<0.0001
Hx DM	20%	22%	25%	23%	<0.0001
On insulin/oral medications	15%	17%	20%	18%	<0.0001
Hx lung disease	8%	10%	13%	11%	<0.0001
Hx cerebrovascular disease	7%	8%	8%	8%	<0.0001
Hx peripheral vasc disease	7%	8%	8%	8%	0.08
Hx cigarette smoking	62%	58%	56%	58%	<0.0001
Canadian class[a]					<0.0001
No angina	28%	16%	10%	16%	
I	2%	4%	5%	4%	
II	12%	14%	15%	14%	
III	23%	29%	30%	28%	
IV	35%	37%	40%	38%	
LV ejection fraction					0.08
<0.30	4%	4%	4%	4%	
0.30–0.49	22%	20%	20%	20%	
>0.50	74%	77%	77%	76%	
Number diseased vessels					<0.0001
0	3%	2%	3%	3%	
1	60%	57%	55%	57%	
2	27%	28%	28%	28%	
3	11%	13%	13%	13%	
LM lesion > 50%	1.8%	2.2%	2.6%	2.3%	<0.0001
LM > 50% or 3VD	11%	13%	14%	13%	<0.0001
LAD lesion > 70%	52%	54%	56%	55%	<0.0001
Procedure priority					<0.0001
Elective	49%	49%	45%	47%	
Urgent	26%	26%	27%	26%	
Emergent	25%	25%	27%	26%	
Salvage	<1%	<1%	<1%	<1%	
Balloon pump	1.3%	1.0%	0.9%	1.0%	0.004
Cardiogenic shock	3.7%	3.1%	3.0%	3.2%	0.001
Procedure performed for myocardial infarction	24%	29%	33%	30%	<0.0001
PCI type					<0.0001
Balloon	12.5%	10.1%	6.2%	8.6%	
Bare metal stent	87.5%	89.9%	13.9%	51.7%	
Drug-eluting stent	0%	0%	79.9%	39.7%	

[a] Not collected in 2006 or 2007.

CABG = coronary artery bypass grafting; CHF = congestive heart failure; DM = diabetes mellitus; HTN = hypertension; Hx = history; LAD = left anterior descending coronary artery; LM = left main; LV = left ventricular; NPR = no prior revascularization; PCI = percutaneous coronary intervention; 3VD = three-vessel disease.

analyses of long-term outcomes beyond the initial hospitalization. The large number of revascularization procedures studied resulted in statistical significance even when clinical differences are modest. Alternatively, changes that were not statistically significant can be viewed as being indicative of no change. Finally, in COAP it was not possible to easily track the same individual who had multiple revascularization procedures. We have attempted to remedy this deficiency by focusing temporal analyses on those unique individuals undergoing a first revascularization procedure.

Conclusions

Our study validates widely held precepts that volumes of patients undergoing CABG and PCI changed dramatically in the past decade. Practice patterns vary signifi-

Table 10. Outcomes of Percutaneous Coronary Intervention (No Prior Revascularization)

Variable	1999–2000 (n = 11,700)	2001–2003 (n = 22,593)	2004–2007 (n = 32,841)	Total (n = 68,134)	Adjusted p Value[a]
Hospital death	1.8%	1.8%	1.9%	1.8%	0.14
Postoperative stroke	0.3%	0.2%	0.3%	0.3%	0.19
Postoperative dialysis	0.3%	0.2%	0.3%	0.3%	0.52
Postprocedure length of stay (days)	2.3 ± 3.6	2.2 ± 3.0	2.2 ± 3.6	2.2 ± 3.4	<0.0001
Red blood cell transfusion[b]	3.1%	3.8%	3.7%	3.6%	0.93
Return to OR for any reason[c]	1.7%	1.7%	1.3%	1.5%	<0.0001
Unplanned CABG same admission (primary PCI)	...	...	0.4%	...	
Unplanned CABG same admission (nonprimary PCI)	...	...	0.1%	...	

[a] Adjusted by multivariate regression model. [b] Not collected in 2006 or 2007. [c] In 2006 and 2007 only return to OR for CABG was reported.

CABG = coronary artery bypass grafting; OR = operating room; PCI = percutaneous coronary intervention.

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cantly from the most updated American College of Cardiology Foundation Appropriateness Criteria Task Force, Society for Cardiovascular Angiography and Interventions, Society of Thoracic Surgeons, American Association for Thoracic Surgery, American Heart Association, and the American Society of Nuclear Cardiology 2009 appropriateness criteria for coronary revascularization. Risk profiles and comorbidities increased for both CABG and PCI in a more variable way. Patients undergoing CABG had an unchanged mortality but improved morbidity. Mortality and morbidity for PCI were unchanged. The long-term consequences of changes in revascularization strategies are unknown and need to be defined.

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INVITED COMMENTARY

Despite remarkable advances in interventional and medical therapy during the past 2 decades and a continuing decline in death, cardiovascular disease remains the leading killer in our country, and, increasingly, throughout the world. The current epidemic of obesity sadly promises to erase medical progress. Therefore the question of optimal treatment will remain a lively and hopefully productive debate for years to come.

Provocative studies such as Clinical Outcomes Utilizing Revascularization and Aggressive Drug Evaluation (COURAGE) [1] have called into question the value of percutaneous coronary intervention (PCI) for patients with stable angina, whereas the data of Hannan and colleagues [2] reveal a long-term mortality benefit for coronary artery bypass grafting (CABG) vs PCI in the real-world setting of the New York State Cardiac Registry. It is in just this milieu of evolving medical, interventional, and surgical therapies that studies such as that presented by Aldea and colleagues [3] acquire added significance.

Tracking all patients undergoing CABG or PCI in the State of Washington between 1999 and 2007, the authors are able to provide clear documentation of changing practice patterns during the past decade. The trends reported for increasing PCI volume, decreasing CABG volume, and the rise and decline of drug-eluting stents and off-pump operations confirm recent reports of national trends. The finding that PCI does not appear to affect ejection fraction or mortality for subsequent CABG, although retrospective, is notable. Unfortunately, the database is limited to admission data; 30-day and long-term mortality rates, readmission rates, and reoperations for complications are all unknown.

Although the authors carefully track individual risk factors through different time periods according to presence or absence of previous PCI or CABG, what is lacking is a clear analysis of relative overall surgical risk over time. The sort of information that Ferguson and colleagues [4] so nicely demonstrated for the decade of the 1990s in the Society of Thoracic Surgeons (STS) population—increasing risk with declining mortality—is not discernible from the data presented. The surgical mortality rate was stable, and morbidity decreased; however, do these trends reflect changing referral patterns or improvements in surgical technique? Did risk factors specifically associated with mortality change over time, possibly reflecting improvements in surgical or medical care? Is there any identifiable pattern of risk factors that would suggest a better outcome for PCI vs CABG?

Based on the completeness of the data in a "real world" setting, the Aldea study is an important signpost in the rapidly evolving landscape of therapeutic interventions for coronary artery disease. As such, it raises more questions than it answers—questions that we hope will be addressed in forthcoming reports.

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